BLUFF MILITARY BASE STORMWATER DISPOSAL: CONSTRUCTION OF A SHAFT WITH AN INCLINED TUNNEL OUTLET TO THE BEACH

Mark Richter, Shakira Sattar, Vinesh Sookan

FIGURE 1 Stormwater shaft

FIGURE 2 Horizontal pipejacked tunnel

FIGURE 3 Reinstatement of slope using geofabric steps

ABSTRACT

The damage caused by erosion on and adjacent to the military occupied part of the Bluff in recent years has resulted in considerable annual expenditure in repairs and maintenance. Major structures, at both the top, eg Block E of the SANDF Bluff Military Base, and the bottom of the slopes have been threatened or damaged by the erosion gulleys, with poorly managed stormwater being the biggest culprit. In 2000 the Client, the Department of Public Works, engaged a team of consulting civil and geotechnical engineers to provide remedial measures for the immediate reinstatement of the badly eroded slope and develop a solution for the long-term management of the stormwater as a whole.

The severely eroded sides of the Bluff dune were repaired using geofabrics to provide resistance to ongoing erosion and to create a stable area for the natural vegetation to re-establish. The very deep erosion gulley was repaired in 2001, but more recently in 2010 overtopping of the contour road on the inland side of the bluff resulted in another large erosion gulley which was repaired and forms part of the subject matter for this paper. In order to ensure that all stormwater is managed the designers opted for a shaft near Block E – an area of high accumulation – which is some 54 metres deep and discharges the stormwater into the ocean via an outfall pipeline, some 139 metres in length, at the low tide mark.

Considerable stormwater pipeline reticulation was also included in the design so that accumulations on areas of the military base could be disposed of via the shaft. Some of the areas on the base do not allow discharge to the shaft because of elevation differences and the stormwater had to be directed into stormwater soakpits which consist of cylindrical

FIGURE 4 Construction of stormwater reticulation

FIGURE 5 (left) Erosion gulley below Block E (2007)
FIGURE 6 (right) Reinstatement of slope

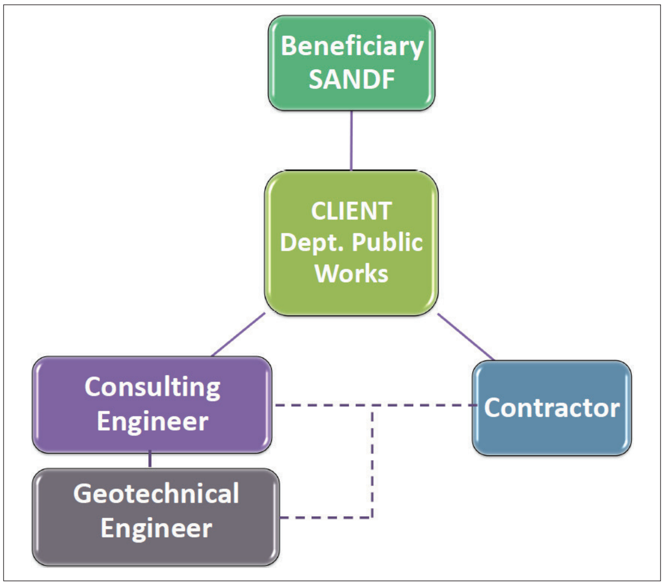
reservoirs installed in the ground as concrete caissons and designed to act as underground detention tanks. At the time of writing the contract was some 95% complete.

INTRODUCTION

The project, initiated by the Department of Public Works, consists of the following main elements:

- stormwater pipe reticulation
- soakaways
- shaft
- inclined tunnel outlet (jacked pipe) connecting to the base of the shaft
- erosion gulley and washaway repair.

The project was awarded in November 2011, and was to have an 18 month contract period. The approximate value of the contract is R20.5 million, however, additional work is likely to result in an increase of this amount by about 5%. The stakeholders of the project are shown in the organogram below:



HISTORY AND BACKGROUND

The damage caused by erosion and landslips on and adjacent to the military occupied part of the Bluff in recent years has resulted in considerable annual expenditure in repairs and maintenance. Major structures at both the top and the bottom of the slopes have been threatened or damaged by the erosion gulleys and related slips. In 2001 poorly managed stormwater within the military base Block E experienced a dramatic loss of soil adjacent to the seaward facing side of the building, caused by a leaking stormwater service over a period of about 6 days (Figure 5). There was thus an obvious need to manage stormwater to prevent large scale erosion.

Early work done by specialist geotechnical and civil engineers on appointment in 2000 from the Department of Public Works identified several alternative locations for stormwater disposal shafts within the military base. The main objective was to upgrade the overloaded stormwater drainage system by replacing existing soakaways and discharge spreaders with several new vertical drainage shafts to link the existing stormwater reticulation systems to a beach discharge outlet. Subsequently, in 2010 a new erosion gulley formed on the west-facing slope of the Bluff and the Client engaged a team of consulting civil and geotechnical engineers to provide remedial measures for the immediate reinstatement of the badly eroded slope and a solution for the long-term management of the stormwater in the SANDF Military Base as a whole. While available funds for the project only allowed the construction of a single shaft at Block E, significant pipeline reticulation was required to connect as many of the stormwater intakes on the military base as possible. Where local gradients precluded the drainage of stormwater via the shaft the balance of the stormwater disposal was carried out using soakpits.

GENERAL SITE DESCRIPTION

The area under review is occupied by the SANDF military base on the northern portion of the Bluff dune ridge bounded by South Pier. The bluff has a relatively flat crest of approximately 0.2 km in width falling away with steep side-slopes (gradients of approximately 1V:2H, becoming 1V:1H on the lower slopes) to the northwest and southeast. A new shaft located at the approximate position shown in Figure 7 at an elevation of roughly 80 m was proposed. An inclined pipejacked tunnel will convey the stormwater from the base of the new vertical shaft to the beach discharge outlet located on the beach.

GEOTECHNICAL INVESTIGATION

A geotechnical investigation was carried out to provide an indication of the ground conditions beneath the military base. Critical aspects such as materials composition, excavation requirements, lateral support, soil permeability and groundwater had to be determined to provide the

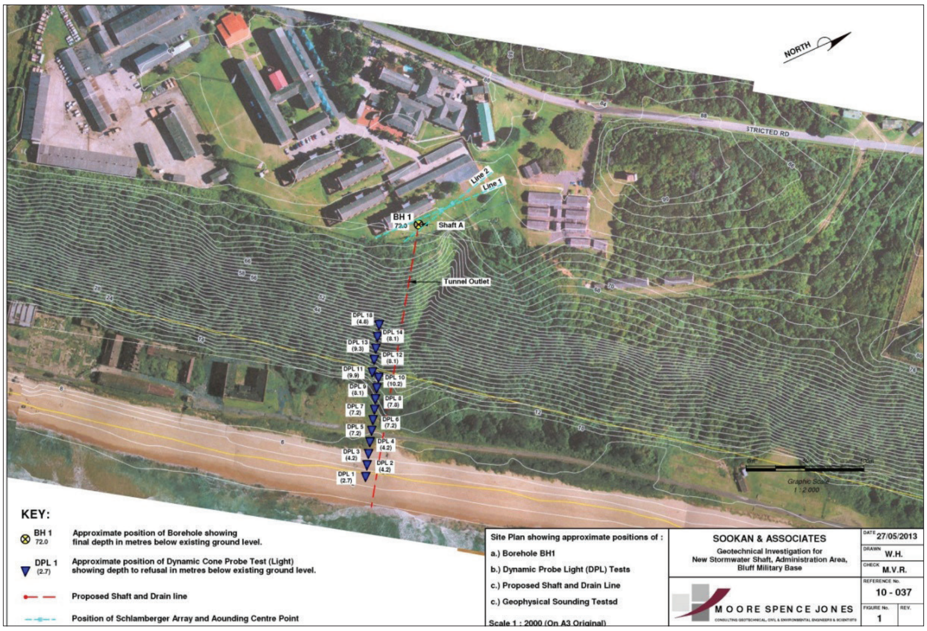


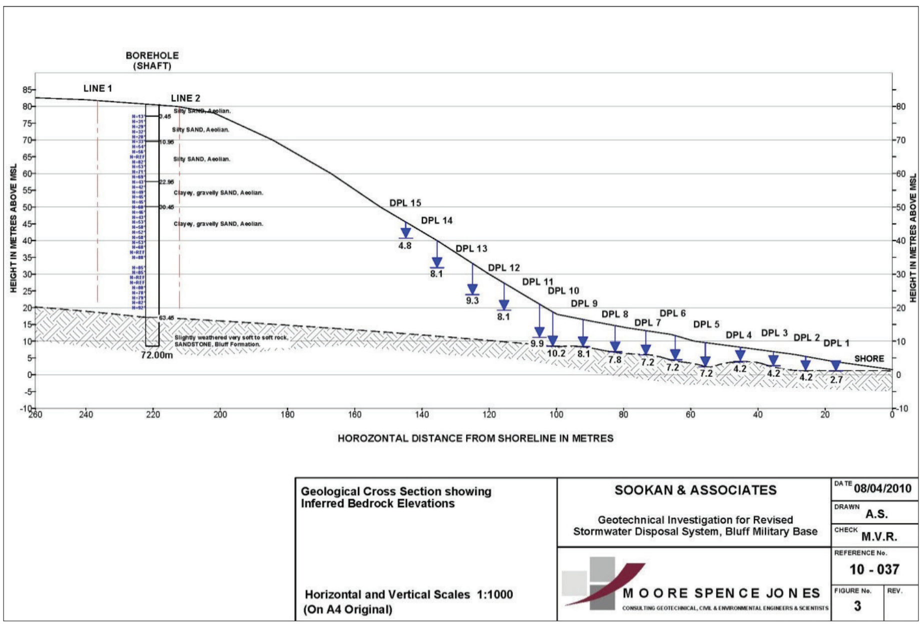
FIGURE 7 Military Base area showing shaft location and route of the tunnel to the outlet of the beach

necessary design for the shaft & tunnel system, stormwater soakaways and the reinstatement of the eroded slopes. The fieldwork comprised Borehole, Light Dynamic Cone Penetrometer (DPL) tests, Geophysical Surveys, and Percolation/ permeability tests. Relevant laboratory tests were also scheduled. At the shaft location one borehole was drilled to a final depth of approximately 72 metres to confirm the ground conditions for the shaft.

Ground Conditions : Tunnel and Shaft

The shaft was sunk through the sandy soils of the Berea Formation. These soils gradually grade into calcarenites and calcareous sandstones of the Bluff Sandstone Formation below a depth of about 30 metres. Ground conditions at the new stormwater shaft can be roughly characterized by six layers according to colour and density differences:

FIGURE 8 Geological cross section showing Inferred Bedrock Elevations



- Layer 1 : 0-3.5 m – Reddish orange-brown, loose to medium dense, silty fine sand
- Layer 2 : 3.5-11 m – Yellowish brown, dense, silty fine to medium sand
- Layer 3 : 11.0-20 m – As above but very dense
- Layer 4 : 20.0-30 m – Yellowish brown, dense, slightly clayey gravelly silty fine sand
- Layer 5 : 30.0-64 m – Yellowish brown, very dense, slightly clayey gravelly silt fine sand
- Layer 6 : 64.0-72 m Bedrock, consists of porous, slightly weathered calcarenite or calcareous sandstone of the Bluff Sandstone Formation.

Groundwater Conditions

Groundwater level exists at roughly sea-level on the edges of the ridge and has a domed profile, rising to the highest level at the centre of the ridge, following a gradient of about 1:12

Materials Classification

The Berea Formation dune sands invariably classify in terms of the USPRA system as A-3(0), are non-plastic and highly erodible. They comprise the following:

- Fine Sand (30% - 40%)
- Medium Sand (50% - 60%)
- Silt and Clay (5% - 8%)

GROUND CONDITIONS FOR PROPOSED SHAFT AND HORIZONTAL TUNNEL

The vertical shaft comprised cast insitu, slip formed Reinforced Concrete structure with a final depth of 54 metres. The tunnel consists of a horizontally jacked inclined concrete pipe with a final length of 139 metres. Given the depth of the dune soils confirmed by the boreholes, Soft Excavation (SABS 1200DM) was anticipated to a depth of about 17m above mean sea level (±53 m below existing ground level. Below this depth calcarenites and calcareous sandstones of very soft rock to soft rock in strength (UCS range 3 to 10 MPa) were anticipated.

DESIGN OF STORMWATER DISPOSAL SYSTEM

Stormwater Pipe Reticulation

The stormwater pipeline reticulation comprises approximately 2 km of trenched pipe. Concrete pipe sizes range from 375 mm to 1 200 mm diameter and have concrete spigot and socket joints. Reticulation for the NavComm area in the military base drains to soakpit caissons, while that of Block E area drains to the shaft. Design incorporates a 1 in 10 year return storm design.

Stormwater Soakaways

The stormwater soakpits comprise 1 800 mm ID concrete pipes which are sunk as caissons. These soakpits are designed as full retention underground tanks. Water will dissipate through 75 mm diameter preformed outlet holes which are stoppered with a geotextile 'socks' filled with stone. The geofabric prevents soil ingress into the soakpits, while allowing the water to dissipate into the soil. Much of the stormwater will dissipate vertically through the base of the caisson which rests on a dumprock

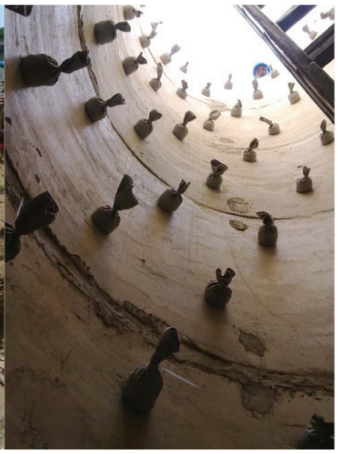



FIGURE 9 (left) Laying of concrete pipes
FIGURE 10 (right) Soakpit caissons 1.8 m diameter, drainage socks protruding from concrete shell


FIGURE 11 (left) Reinforced concrete shaft – slip form method
FIGURE 12 (right) Jacking pit for pipejacked tunnel

mattress. This mattress was constructed by under-excavating below the caisson base and the dumprock placed in the void.

Stormwater Shaft and Inclined Tunnel (Jacked Pipe)
The shaft was let out in the tender as a design and construct. It is 54 metres deep and comprises a 2.8 m OD and 1.8 m ID circular reinforced concrete section. It was constructed using slip form methods and concrete design strength is 35 MPa. The outlet tunnel consists of a 139 m long jacked section of 1 200 mm diameter ID pipe. It is a Class 100 D pipe.

Repair of Erosion Gulley on inland side of bluff dune
Part of contract comprised the reinstatement of the bluff dune slope where a severe erosion gulley formed when a scour valve on a water supply pipe was opened in error. This caused a failure of the discharge pipe and resulted in the erosion of the slope. This erosion gulley is located above the harbour facing onto Durban Bay below the Harbour Control Tower. The extent of the erosion gulley is some 1 000 m^2 and 3 m deep.

Reinstatement of the slope involved the following:
- routing of stormwater at road level
- slip Repair using geofabric soil reinforcement techniques.

CONSTRUCTION PHASE

Pipelines
The construction of the pipeline reticulation was carried out with the following features providing numerous challenges to the contractor:
- non-cohesive sand, generally of very loose and loose consistency requiring lateral support since there were space constraints preventing battered excavations
- shored trenches were generally required, with one section of trench some 4 metres deep experiencing serious collapse
- many unknown services, some very old, caused significant delays to the trenching operation.

FIGURE 13 Collapse of poorly supported trench

FIGURE 14 Dynamic loading on caisson

FIGURE 15 Slip formed caisson shaft

FIGURE 16 Calcarenite bands encountered in pipejack

FIGURE 17 Interjack station to relieve sleeve friction

FIGURE 18 Location of jacking pit near beach outlet for the tunnel

Shaft

The shaft comprised a slip-formed caisson. The first two pours were required to provide a cutting edge for the caisson which with successive poured sections, sink of its own weight. Due to hard calcareous bands encountered at shallower depths than indicated from the drilling results, the caisson had to be assisted in sinking by applying kentledge and dynamic loading.

Shaft sinking was impeded by sandstone bands and concretions from as shallow as 16 m below ground level. These sandstone lenses were not identified in the borehole cores until about 62 m depth. It was confirmed that the grinding action of the core-barrel pulverised the weak sandstone and the arisings from the borehole resembled dune soils, confirming that there is thus no easy method to identify sandstone layers/concretions from normal drilling methods. The Contractor had to use water jetting methods and dynamic loading as well as applying Kentledge to break through these unexpected layers.

Pipe Jack

The horizontal tunnel was advanced from the beach towards the shaft by using pipejacking methods. Due to the considerable length of the tunnel and the build-up of friction forces between the tunnel shell and the in-situ dune soils, frequently exacerbated by the hard calcareous sandstone or calcarenite bands or lenses encountered, inter-jack stations were required every 7 pipe lengths (17.5 m). Typical jacking pressures were of the order of 25 kPa, but increased to 30 kPa when calcarenite lenses of bands were encountered. Friction forces were reduced by injecting bentonite into the pipe-soil annulus void to lubricate the pipe and reduce jacking pressures.

Erosion Gulley repair

The repair of the erosion gulley comprised the use of a soil reinforcement technique consisting of geofabric steps. The steps were constructed using a wrap-around 'geostep' design, involving steps constructed by the use of insitu soils folded or wrapped back into the slope using a geotextile, and then covered with soil and vegetated. The steps tied into the natural slope angle which ranged between 33° and 38° in order to allow for reinstatement of the original slope. Removable metal forms were used to construct the steps uniformly and to ensure the correct slope angle was obtained. Access on the slope was fairly difficult and importation of soil from the shaft/tunnel part of the site to reinstate the eroded slope required the use of a hopper and chute system to deliver soil to the area of step construction.

It is worth noting that during March 2013 high rainfalls occurred and another erosion gulley occurred adjacent to the one under remediation, indicating that the real cause of the problem is related to the inefficient drainage of the concrete contour road below the Harbour Control Tower. As a result additional work has been requisitioned as a variation to the contract. This work will involve the remediation of the culvert on the road and installation of a pipe of adequate size to remove the water downslope to the stormwater management system of the harbor area below.

CONCLUSION

The repair to the erosion damaged areas within the Bluff Military Base is currently underway and represents the culmination of several phases of investigation into the adoption of a comprehensive stormwater management system. The dune soils making up the Bluff in this area are highly dispersive and erodible. Even minor events of rainfall or leaking services which result in uncontrolled runoff have the potential to cause significant erosion damage.

The current contract, some R20.5 million in value, involves the design and construction of a central stormwater shaft some 54 metres deep near Block E where the most severe erosion damage has been noted to date. A

FIGURE 19 (left) Washaway repair. Note old gabions installed after earlier event
FIGURE 20 (right) Reinstatement of slope using geofabric steps

FIGURE 21: Soil Hopper

FIGURE 22 Chute to deliver soil onto slope

horizontal tunnel some 139 metres in length connecting to the shaft will provide an outlet for the stormwater to discharge into the ocean. About 2 km of stormwater pipe reticulation will discharge into the shaft. Where gradients in some areas do not accommodate reticulation, the stormwater will be disposed of by several large stormwater caissons.

Eroded slope areas have been remediated using geofabric steps to reinstate the slope to natural gradients. The steepness of the slope has contributed to difficult working conditions and the use of hopper and chutes have been necessary for the movement of soil to areas requiring reinstatement. Significant upgrading of the stormwater pipes was also carried out to ensure adequate capacity is available to cater for storm events.

A relatively detailed geotechnical investigation was required to define geotechnical design parameters for the works.

The construction phase has encountered many problems related to the erosive nature of the soil, the loose collapsing sands which require shoring of trenches, and the shallower than anticipated calcarenite or calcareous rock bands within the dune soils, giving rise to challenging ground conditions for shaft sinking and tunneling in general.

While the contract nears completion, additional vulnerable slope areas have been identified, the remediation of which are being handled as part of the current contract.

While the current contract cannot be all encompassing, it will go a significant way in ensuring that the sensitive and iconic Bluff landform is protected from the erosive effects of stormwater.